

Excerpt from June 2004 Fermilab Physics Advisory Committee Recommendations

E-918 BTeV (Joel Butler / Sheldon Stone)

Introduction

The DOE Office of Science conducted a technical, cost and schedule review of the BTeV experiment in April, 2004. While the outcome of that review was positive with respect to technical and cost issues, the proposed schedule was judged to have inadequate float. In light of this, the BTeV collaboration has proposed a new schedule with a staged installation. The bulk of BTeV will still be installed in the summer of 2009; however, a fraction of the electromagnetic calorimeter and elements of the straw tracker and RICH are scheduled to be installed in the summer of 2010. The Committee has been charged with reviewing the initial and ultimate physics potential of BTeV in the context of the proposed staged schedule.

The completed BTeV detector will enjoy significant advantages over LHCb, including a superior, inclusive triggering scheme, a three-dimensional high-granularity pixel tracker, a higher resolution electromagnetic calorimeter, and a DAQ system that allows for high event rate to mass storage. Thus, despite the higher b-quark cross section at the LHC, each fb^{-1} of data is expected to yield a superior physics payoff for BTeV. The Committee found nothing in the staging scheme that will diminish these ultimate physics capabilities of BTeV.

The proposed staging preferentially maintains charged-mode capabilities in order to remain competitive in areas of LHCb's relative strength. Even so, BTeV will have significant physics capabilities in neutral modes, where LHCb is less capable, during Stage 1. By the summer of 2010, BTeV could have acquired about 1.0 fb^{-1} with their Stage 1 detector, and LHCb could have about 1.8 fb^{-1} . The Committee reviewed a series of physics studies that compare initial results from a staged BTeV to LHCb. The results of these studies show that BTeV will become the superior experiment essentially as soon as BTeV data are available. Since LHCb will be online 1-2 years before BTeV, LHCb will have some opportunities for new physics discoveries. However, this statement is true even if BTeV is not staged.

The Committee finds the studies presented to be sound. The Committee expects BTeV to be competitive with LHCb as soon as BTeV starts analyzing data, giving it a good chance to participate in the initial measurements, which should have significant discovery potential. The Committee reiterates that nothing in the staged schedule will affect the expected superiority of BTeV on a wide range of compelling heavy flavor physics topics. In light of these findings, the Committee unanimously endorses the staging plan for BTeV.

Detailed Discussion

The Committee was presented with two important estimates for predicting the degradation in performance of the staged BTeV experiment. For analyses using charged modes that require a flavor tag, the staged configuration has approximately 75% the efficiency of the full BTeV, and for analyses that use decay modes with one π^0 or η and need a flavor tag, the

staged configuration is approximately 45% as efficient as the full BTeV. Using these estimates, and further assuming the worst-case scenario, namely a physics analysis completely dominated by statistical errors, we can readily predict the increase in the uncertainty that a staged BTeV would have over the full BTeV for the same integrated luminosity. For a tagged charged mode, the uncertainty is increased by about 13%, and for a tagged neutral mode, the uncertainty is inflated by 49%. This gives a quantitative summary of the relative performance of a staged and full BTeV.

Additional factors should be considered when trying to compare initial running of a staged BTeV and LHCb. First we consider the expected luminosity for each detector. BTeV asserts that beyond 2008, the Tevatron will deliver 1.6 fb^{-1} to CZero in each ten-month running period per year. This assumption is consistent with the Tevatron Upgrade Project plan (which has a *Design* goal of $2.1 \text{ fb}^{-1}/\text{year}$ for 2008), and is within a factor of three of the present Tevatron performance. The Committee notes that the *Base* performance goal, judged by the recent Lehman review to be “highly achievable,” would achieve 1.2 fb^{-1} per year, or 75% of BTeV's assumed luminosity. In fact, given the recent decision to build an optimized interaction region at CZero, the anticipated $\sim 1.6 \text{ fb}^{-1}$ per year is even more likely now than it was when BTeV was previously recommended for approval by the PAC and P5, and there could yet be further gains - not assumed here - from running the Tevatron with only one interaction region. Thus the Committee finds it reasonable to assume that the Tevatron will deliver $\sim 1.6 \text{ fb}^{-1}$ per annual run period beyond 2008, and that during the period when BTeV expects to run for six months with their Stage 1 detector, the experiment should integrate approximately 1.0 fb^{-1} .

Luminosity to LHCb is estimated using the note by Collier, which indicates that they will obtain 0.1, 0.6, and 0.8 fb^{-1} in the years 2007, 2008, and 2009, and 0.8fb^{-1} in each subsequent year. The 0.1 in 2007 is not likely to be physics-quality data. Assuming half of the 2010 luminosity is integrated before the summer, this leads to a best-guess estimate of 1.8 fb^{-1} for LHCb by mid-summer of 2010. Note that after accelerator commissioning, BTeV should enjoy a factor of two advantage in integrated luminosity per year. This arises from the difference in planned yearly run periods, 10 months for the Tevatron and about 160 days for the LHC.

BTeV is commissioning during 2009 and 2010, while LHCb will be commissioning more slowly during low luminosity running in 2007 and 2008. The impact of commissioning is impossible to quantify reliably. BTeV argues that “both experiments have to commission so the losses cancel out”. We hold some doubt about this statement. In all likelihood, BTeV will lose more useful luminosity to commissioning and other start-up factors, somewhat eroding their physics advantage to LHCb. As for the relative accelerator performance, the Tevatron turn-on in 2009 is more predictable at this time than early LHC performance, leaving a bigger downside uncertainty on LHCb luminosity. This could result in an advantage to BTeV during early running.

Finally, BTeV claims that it will write 1 kHz of B decays to tape and that LHCb will write 200 Hz, a factor of five in BTeV's favor. There is reasonable evidence obtained by private communication that LHCb can do better than 200 Hz - perhaps by a factor of two. However, 200 Hz is the figure that has been documented and subjected to internal and external review.

The above discussion leads us to believe that for running before the summer of 2010, BTeV's statistical uncertainties will be degraded by about 13% compared to an unstaged BTeV, for physics analyses for which we would expect LHCb to be competitive. The Committee does not believe the performance difference between a staged and an unstaged BTeV is significant. The luminosity disadvantage for BTeV before the summer of 2010 is not overwhelming, and once BTeV starts taking data, that disadvantage should be compensated for rather quickly.

The above discussion is simplified, but complements the more detailed studies presented by the BTeV collaboration. BTeV has conducted Monte Carlo studies to evaluate the impact of staging on measurements of four key physics modes, and compared the results to LHCb projections. The studies give expected uncertainties vs. year or for a given integrated luminosity. We summarize as follows.

1. γ , the phase of V_{ub} , from $B_s \rightarrow D_s K$.

This analysis uses an all-charged decay mode and requires flavor tagging, for which the staged configuration will be 75% as efficient as the full BTeV. At the end of 2010, BTeV should measure γ with an uncertainty of approximately 11° , while for LHCb the uncertainty at the same point in time is expected to be about 14° . If BTeV runs in full configuration from the start, their uncertainty would be approximately 10° by the end of 2010. We consider the difference between staged and unstaged BTeV to be unimportant in the first year, and it is also unimportant in the long run, where BTeV is expected to measure γ in this mode with twice the precision of LHCb.

2. Determination of α from $B \rightarrow \rho \pi$.

This mode involves reconstructing a π^0 , something BTeV – staged or full – should do with significantly better efficiency and mass resolution than LHCb, due to its finer-grained, higher-resolution calorimeter. BTeV estimates that with 2 fb^{-1} of data and their Stage 1 detector, an uncertainty on α of 6.3° can be obtained. With the full BTeV, 2 fb^{-1} yields an uncertainty of 4.2° . LHCb does not provide an uncertainty on α in its TDR. However, the BTeV collaboration estimates that with 2.0 fb^{-1} , the LHCb uncertainty will be approximately 12° . The Committee agrees that BTeV's performance should be superior in either configuration.

3. Determination of χ .

A measurement unique to hadron collider B experiments is the measurement of the B_s mixing phase, χ . Here BTeV can take advantage of its better capability on neutral decay modes. Using 2 fb^{-1} they estimate their uncertainty in χ will be 1.1° for a Stage 1 detector, and 0.7° using the full detector; the corresponding resolution for LHCb, which uses an all-charged mode, is 3.7° . Ultimately, BTeV should achieve a precision of about 0.5° , which is small enough to measure the expected Standard Model value; for LHCb the corresponding resolution is about 2° . The Committee judges BTeV to be superior in both the short term and the long term, independent of staging.

4. Measurement of $K^*\mu^+\mu^-$ branching ratio and decay kinematics.

This electroweak penguin decay has rich potential for exploring new physics, and is one for which LHCb, with its muon trigger, is well suited. In this case BTeV and LHCb estimate their quality factor QF (roughly the square root of the normalized event yield weighted by the signal purity) to be comparable in the short term and long term. This is true whether BTeV is staged or unstaged.

These studies lead to the conclusion that the staging scheme has little impact on the BTeV performance in the first year of its running, and has no impact at all on the expectation of superior long term performance by the BTeV detector in most analyses.

Nevertheless, the Committee notes that LHCb will start one to two years earlier than BTeV, and in any analysis this is certainly an advantage for making early discoveries. If γ measured in $B_s \rightarrow D_s K$ turned out to be large, say 125° , LHCb will discover it first. If χ turns out to be large, say 5° or 6° , LHCb will discover it first. This is simply the advantage of being online first, and is largely unaffected by any question of BTeV staging. The Committee notes that any discovery made by LHCb in this period will feed the physics program of BTeV for the long run, and the ultimate superiority of the BTeV detector ensures that BTeV will write the final chapter in such cases.

General Observations

We conclude with several observations relevant to maximizing BTeV's discovery potential:

1. The BTeV collaboration has indicated that they will attempt to avoid the necessity of staging altogether, through a combination of additional non-DOE funding, additional forward funding, and minimizing the necessity of using the float in their schedule. The Committee encourages these efforts.
2. It is important to minimize the time needed for commissioning of BTeV after the detector goes on-line. The BTeV collaboration has a stated goal of completing their trigger and DAQ commissioning in the first month of running, which is quite aggressive. In recognition of the importance of rapid turn-on, the collaboration is making plans for extensive pre-commissioning of individual subsystems and of horizontal and vertical slices of the full detector. These efforts should be continued, extended where possible, and developed into an overall detailed commissioning plan.
3. Timely completion of BTeV will require augmenting the collaboration. In addition, rapid data analysis after BTeV turn-on will depend upon having a sufficient pool of physicists devoted to analysis, even as the staging activities are being completed. Rapid analysis will also require that offline software is ready near the time that BTeV turns on.

In conclusion, the Committee notes that the compelling physics reach of BTeV is largely independent of detailed assumptions about their modest staging scheme. The BTeV experiment will have unique sensitivity to effects from new physics at multi-TeV scales. The Committee expects that BTeV physics results will play an exciting and essential role in understanding new physics in the LHC era.